RP 301 Wind Turbine Blades

The following recommended practice (RP) is subject to the disclaimer at the front of this manual. It is important that users read the disclaimer before considering adoption of any portion of this recommended practice.

This recommended practice was prepared by a committee of the AWEA Operations and Maintenance (O&M) Committee.

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Purpose and Scope

The scope of “Wind Turbine Blades” addresses proper purchase, transportation, maintenance, repairs, and balancing of wind turbine blades.

Introduction

The purpose of this document is to provide turbine manufacturers, owner/operators, and independent service providers in the wind energy industry with a description of the best maintenance, inspection, and repair practices for the blades and nose cones employed on wind turbine rotors. These best practices are to serve as a guideline with the understanding that economics will drive the actual implementation decision at each individual wind farm.

Wind Turbine Blades

1. Inspections

1.1. Areas of inspection

Blades need to be checked in detail and their condition is to be documented. Irregularities and damages are to be detected and a recommended repair date specified. The blades need to be checked in detail by a reputable technical expert. Scope and type of inspection are taken from the following table. (*See Table A*)

Table A. Areas of Inspection.

Component to be Checked	Type of Inspection and Check-points	Minimum Inspection Frequency Every 2 Years*
Blade Body	visual evidence of cracks, air pockets, delamination, drainage, protective film and erosion of the leading edge, lightning protection system, spark gap documentation of blade, pitch angle documentation of blade moment balance	**Selected inspections may be needed after environmental incident events. Lightning storms, severe winds, hail, etc.*
Flow Elements	turbo rills, vortex generators, micro swirl prong bands, gurney flaps	
Visible Profile Accuracy	characteristics of the trailing edge, light reflection	
Blade Inner	If technically possible, the blade should be checked from the inside. It is important that the area is stable enough. delamination, bars: cracks, finish of web adhesion	
Blade Sealing To Hub	oil in the blade, lightning protection system within the blade	
Extender	corrosion, bolts, weld seams	
Wind Turbines Tip Stall Mechanism	play, grime, adjustment, crack, guide tube, damping plate, index pins, bolts and cross bolts, function	
Wind Turbines Blade Pitch Adjusting Device	bearings, grease condition, play in mechanism, leaks, gear tooth contact pattern, connecting rod, oil in the blade	
Wind Turbines Blade Pitch Adjusting Cylinder	leaks, mechanical stops, blade adjustment locking device	
Wind Turbines Pitch Return Element	function, tighten the accumulators	
Wind Turbines Pitch Electrical Cabinet	tighten within hub	
Bolts, barrel nuts, bushings	Check torque, wear, corrosion	

1.2. Pre-Purchase Audit

In addition to the inspections listed above, documentation on the blade set should include the blade weights, the blade centers of gravity, manufacturing date, and repairs made to the blade before delivery, which should include rework to bond lines, lamination defects (wrinkles), dry spots, and leading edge reshaping. This information should be kept with the rotor set's O&M record for life of rotor.

1.3. Delivery/Commissioning Inspections

Assure all rotor sets are assembled as specified. Assure all surface defects since leaving OEM are resolved properly. Major pre-purchase repairs should require confirmation of balanced blade set. Confirm all rotor sets hung in proper/consistent order, e.g. A-B-C, etc.

1.4. Environmental Incident Inspection

Immediately following an environmental incident a ground based visual inspection for obvious blade damage should be conducted. Based on those observations, additional inspections from the list above should be conducted.

1.5. On-going Inspections

Part of a consistent O&M recommended practice is to have a documented on-going inspection plan where all turbines are inspected on a regular basis. Extra inspections on problematic blades are highly recommended, as are higher inspection rates on previously repaired blades.

1.6. Pre-End of Warranty Inspection

The key to the end-of-warranty inspection is to plan well ahead of the end-of-warranty in order to better plan out this inspection. Planning ahead is important because a single inspection may require a follow up inspection prior to bringing any warranty issue to the OEM before the warranty period is completed.

2. Transportation and Storage

2.1. Transportation

All blades need to be shipped in compliance with the OEM transportation specification. Recommended practice would be to have this specification on-site prior to the shipping of the blades to assure that all specifications are met, and in case any conflicting issues arise that deviate from this specification. Specific things to inspect are the bracing and support of the blades. Inspect for proper cushioning and support on the leading edge, proper side support on the shell body so as not to induce longitudinal cracking, proper cinching of cargo straps so as not to damage trailing edge, and proper bracing on the blade to prevent adverse flexing during transportation.

2.2. Storage

Storage of blades needs to be different for the intended length of storage. Short periods of storage, such as staging for installation, can be varied as long as the blade is not exposed to undue mechanical strain or an environment that would compromise the exterior structure of the blade. Long term storage needs to address the following:

- Protection from UV light
- Root bolts sealed from moisture
- Blade protected from rain, dust, and foreign objects, including small animals and insects, from entering the interior of the blade
- Blade properly secured to the ground to prevent damage in high winds
- Blade properly supported to mitigate any mechanical stresses on the structure of the blade (leading edge, trailing edge, shell wall)

3. Maintenance

Preventive maintenance schedules have repeatedly shown to be more cost effective than responding to issues as they arise. There are many formats for maintenance schedules, but the key is to incorporate one that will be followed consistently by the site team. This may include having a third party conduct all PMs and repairs on a long term contractual agreement.

There are many visual and auditory inspections that can be used as part of the preventative maintenance plan which require little effort and do not require interrupting the generation of power. High speed digital photography for identifying lightning strikes, trailing edge cracks, and foreign object strikes can be conducted from the ground. Changes in the sound of the rotor set spinning can also be

3. Maintenance
(continued)

Typical preventative maintenance plans will address the areas mentioned in Table A. Additionally, as the rotors age, a representative set of rotors should be physically inspected for defects, wear, and damage by some form of blade access. The set of rotors physically inspected should change each year, so as to have each rotor set physically inspected on a regular basis. This varies from farm to farm, but a 2 to 10 year rotation is common. Items identified with these inspections could alter the rate of inspection and should be used to plan repairs so as to minimize costs, e.g. bunching repairs to lower cost per turbine repaired.

The maintenance data collected for each blade and rotor set needs to be retained with the rotor set for the life of the farm and it needs to be reviewed on a regular basis for potential predictions on power loss, potential failures, etc.

Blades and rotor sets that continuously have more issues, should have their PM scheduled more frequently to minimize reactive maintenance and to aid in understanding trends for the rotor set.

4. Repair

All repairs whether under warranty or past the warranty period should be conducted with OEM approved materials. The primary key to all repairs is to return the blade to the same physical strength, shape, and weight as when it was commissioned. Usually the exact same manufacturing process cannot be used to facilitate the repair, thus the repair may be thicker or heavier in the repair location to obtain the same structural strength as in the original location or it will be lighter or not as structurally strong to return the location to the same surface profile. Depending on the location and its critical performance function, the repair team will need to decide how best to complete the repair.

4.1. Safety

Repairing and maintaining rotor sets creates additional safety concerns beyond the concerns already presented on every wind farm. Safety needs to be foremost in all maintenance and repair programs. The information below is meant to be adjunct to an existing site safety program. As noted above in the SAFETY NOTICE, this information is meant for awareness and all implementers of the processes are responsible for determining appropriate safety, security, environmental, and health practices or regulatory requirements.

4.1. Safety
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4.1.1. Fall Protection and Rescue

All personnel that access the nacelle area of a wind turbine should be trained and certified to safely climb the tower and to perform self and others rescue. Personnel should be trained in the dangers of working at a height, how to use and maintain lanyards, fall arrest harnesses, and positioning equipment and other climbing gear. In addition, personnel should be trained in the correct methods of dealing with emergencies including suspension trauma and rescue.

Testing and Certification should be obtained from a recognized third party organization such as ENSA, ANSI, or NIOSH standards, which should include:

- Safety awareness
- Equipment fitting
- Care and inspection of equipment
- Risk assessment
- Restraint
- Fall arrest
- Work positioning
- Rescue
- Anchor selection
- Evacuation

4.1.2. Aerial Platform Competent User, Safe Access and Rescue

External servicing of the turbine's blades can be performed up-tower utilizing suspended platforms or crane man-baskets. It is critical that service personnel be trained and certified in the operation of vertical lifeline systems, rigging, safe operation of the platform, and self-rescue and assisted recue using ANSI approved automatic control descent devices.

4.1.2. Aerial Platform Competent User, Safe Access and Rescue
(continued)

Specific areas to be trained and certified include:

- Safe use of vertical lifelines
- Establishing a safe work area
- Platform and rigging equipment inspection
- Rigging
- Pre-lift testing
- Platform components and assemblies
- Safe operation of the platform
- Tag line operation
- Assisted rescue
- Self rescue
- Coworker rescue
- Sling angles
- Sling ratings
- Anchor point requirements
- OSHA requirements

4.1.3. Rope Access

In addition to Fall Protection training, service personnel should be specifically trained and certified to SPRAT or IRATA standards for safe access strictly by rope suspension. Personnel should be trained and experienced in the evaluation of rope access equipment and systems, be able to perform access techniques, and be competent in rescue procedures.

Specific areas of training and certification should include:

- Safety standards and documentation
- Methods of access
- Care, inspection, use, and limitations of equipment
- Knots
- Rigging
- Anchoring
- Ascending and descending
- Rope-to-rope transfer
- Structure climbing
- Assessing risks
- Self and co-worker rescue

4.1.4. OSHA 30

The OSHA 30 program provides training in general safety practices for construction and industrial environments.

Specific areas of training are:

- OSHA standards for hazardous conditions and practices
- OSHA's general safety and health provisions
- Occupational health and environmental controls
- Personal protective equipment
- Fire protection and prevention
- Rigging
- Welding and cutting
- Electrical standards and hazards
- Scaffolding
- Fall protection
- Excavations
- Concrete and masonry
- Decommissioning and demolition
- Ladders
- Hazards of confined spaces

4.1.5. First Aid/CPR

Due to the fact that most wind farm sites are in remote areas, it is critical that all field personnel be trained as first responders in applying first aid and CPR. OSHA or American Red Cross guidelines should be followed so that personnel can recognize and care for a variety of first aid emergencies and perform CPR and care for breathing and cardiac emergencies.

4.1.6. Confined Spaces and Respirators

Working within the rotor and especially inside of wind turbine blades require personnel to be trained in confined space access and the proper use of respiration gear. Training and certification for personnel should be done in accordance with OSHA 29 requirements and include areas such as:

- Confined space identification
- Hazard evaluation
- Behavior of gases
- Oxygen deficiency
- Equipment use and care
- Respirator fit
- Ingress and evacuation

4.2. Skill Levels

Blade repairs tend to fall under two primary divisions: cosmetic repairs and structural repairs. Care is needed in assuring that appropriate training and skill levels are available for either type of repair. A simple cosmetic repair, if not performed correctly, can result in a loss of generation power and potentially lead to additional repairs and failures. On-site or independent service providers have varied skill levels for various types of repairs. This can include not only the type of repairs, but also the blade access techniques, scheduling availability, and experience with various repair options and turbine platforms. Up front discussion on these points will prevent issues after a repair is contracted and started, e.g. an excellent team for changing out a pitch motor may not be the best choice for repairing a lightning strike repair.

Regardless of resources being used, accreditation through several programs and technical schools for composite repair should be part of the minimum acceptance level for skills to conduct on-site composite repairs. Such programs include ACMA CCT program for Wind Blade Repair. AWEA maintains a list of the wind turbine technical training schools.

4.3. Blade Repair Steps

4.3.1. Have an agreed plan on what inspections for damage are to be reviewed. This should be in written form and signed by all parties.

4.3.2. Obtain all background information on the damaged area. This should include any drawings, ply orientation, type of resin/adhesive, laminate schedule, and previous repairs.

4.3.3. Conduct a complete inspection of the damaged area. If appropriate, use remote viewing equipment or another safe approach to inspect the interior at the damaged location. The intent is to determine the size of the damage and potential repair prior to starting the repair process.

4.3.4. Once completed, obtain an agreement with site owners, site operators, and the repair team about potential repair options needed to correct the damage. Obtain agreement to conduct further inspection to ascertain the extent of the damage.

4.3.5. After cleaning the damage location, remove the exterior gel coat or paint system to obtain a complete visual for the damaged area. This should be done only with a fine grain abrasive.

4.3. Blade Repair Steps
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4.3.6. Once the entire area of repair has been exposed, the area should be marked and photographed and a detailed report on what steps and materials will be needed to complete the repair should be written. This should include measurements of the amount of scarf needed for each composite layer, the method of resin application to be used, the types of resin, and even the types of tools and processing aids to be used.

4.3.7. The site team, owners, and the repair team should have full agreement on the repairs based on this report prior to starting the repairs. This agreement may be used as the basis for the repair costs and repair warranty.

4.3.8. The repair team should document all steps in the repairs with photos and cite the processing steps and materials used. The approximate weight of the materials used is also of value.

4.3.9. The finished report on the damage and the repairs should be kept as a permanent part of the blade's maintenance record.

4.3.10. For repairs where no composite needs to be replaced, such as replacing a pitch motor, replacing surface mounted devices, or repairing a leading edge, the above mentioned steps of inspecting the damage, recording with photos, a written report with proposal options for repair, obtaining agreement on the repair and its timing and costs, followed by conducting the repair, documenting all steps to remove and replace the damaged components, and retaining the documentation with the maintenance records for the blade/rotor set should also be used.

5. Rotor Balancing

5.1. Expectation, Inspection, and Documentation

Most, if not all, blades are balanced and matched for a rotor set at the OEM location. Assuming that the set of blades remain a set on the turbine, the blades should be balanced.

Balanced rotor sets can lose balance by a change in material weight or by a change in material strength. It is recommended that inspections for rotor balance be made after a major composite repair or after noting differences in blade deflections within the rotor set at a given wind speed.

5.1. Expectation, Inspection, and Documentation
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It is also possible to have a blade increase in weight due to moisture uptake from a porous gel coat, plugged drain hole, or prolonged exposure of blade core material to the environment, etc. This should also warrant an inspection of the rotor balance.

Dynamic balancing should be required any time a substitute blade is needed to complete/repair a rotor set.

As with all maintenance inspections and repairs, the balance measurements should be kept with the rotor set records for the life of the turbine. This should include the blade number, the location on the blade where weight was added, the amount of material added, and the final balance achieved.

5.2. Static and Dynamic Balancing

Static balancing should be kept to a minimum, with dynamic balancing desired. The blades arrive at the farm intended to be part of a balanced rotor set. Confirmation of this should be conducted prior to installing a rotor set. There are many views on balancing. A statically balanced rotor should be a balanced set but it does not mean that it is dynamically balanced. Only after being assembled and hung can the set be tested for its dynamic balance. There are varied ways to determine if the rotor set is out of balance, including auditory, “bumping” the set on a windless day, and correlating data as to which rotor sets are always last to spin up in light winds.

Upon finding a rotor set which needs to be brought into balance, weight should be added to the lightest blade. Weight should never be removed from the heaviest blade. Many OEMs build into the blades “weight boxes”. These confined spaces along the blade are intended to be used for the infusion of dense curable resins to adjust the balance as needed without having weights break free and rotate within the blade and/or reduce the structural strength of the blade.

6. Things to Avoid

When inspections indicate the need for repair, do not unduly delay the repairs. Added costs to make repairs to blades as the need for repair grows may eliminate the ability of the blade to be repaired, e.g. a blade in need of repair where moisture is allowed to egress into the blade core materials could potentially make the blade repair costs higher than the cost of total blade replacement.

7. Additional Suggestions

Conduct site visual inspections with high speed video/camera, telephoto lens, and laser pointers. Lag measurement of blade tip can be an indicator of trailing edge split. Tip offset from tower can indicate shear web weakness, stress cracking near root, or pitch imbalance. Use such low cost internal audits to evaluate the scope of the need for external evaluations and repairs.

Require dynamic balance information on all new installs after the rotor set is installed. Confirm that the information is still within the specification limits.

Keep repair records for all forms of repairs to each blade.

Require of OEM all repair information on any post fabrication repairs. This should include the location and type of repair, method to repair, and materials used to repair. This would include all repairs conducted as the results of transportation, storage, and installation prior to commissioning. This would also include all NCRs (non-conforming reports) from manufacturing.

Request lightning protection system readings recorded from manufacturing.